REAR SEATED OCCUPANT SAFETY IN FRONTAL IMPACTS

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ABSTRACT

Rear seating systems are still being used in military vehicles as well as in some civilian 4 Wheel Drive (4WD) vehicles. Very limited research work is available in regards to the safety of a rear facing seated occupants in a frontal impact crash. This paper describes a new energy absorbing rearward facing seating system which can be used in a 4WD vehicle to attenuate the deceleration forces in a frontal impact. A series of dynamic sled tests on prototype seats were conducted. A 50% male Hybrid III dummy was used for the sled tests. Both the dummy and the seat were subjected to a 49km/h speed change where the forward crash deceleration was 22 g's over duration of 100 ms with the seat and dummy positioned backwards. A MADYMO model was then developed and calibrated against the sled test data.

In the calibration process attention was focussed on the head and chest decelerations in the forward direction as well as on the maximum energy absorbed by the prototype seat. Once the model was calibrated it was then used to simulate the same frontal crash conditions where a 95% male and a 5% female Hybrid III dummy respectively were seated in the prototype seat.

The prototype seat, the sled test results, the simulation models and resulting decelerations and injury outcomes are described in the paper. This study showed that by using an energy absorbing seating system, the crash deceleration can be effectively attenuated and occupant injuries significantly reduced in comparison to conventional seating systems.

INTRODUCTION

The Australian Army is equipped with Perentie 4x4 vehicles which are based on the Land Rover 110. One of the variants used is a Regional Forces Surveillance Vehicle (RFSV). The RFSV has a crew of three personnel; two occupants sit in the front of the vehicle and are provided with three point lap sash seatbelts. The third crew member sits in a rear facing seat and is provided with a lap belt as the photographs show in Figure 1. As a result of developments undertaken initially by Project TRANSAFE and subsequently Project OVERLANDER to improve the occupant safety systems, the restraints where changed to a harness. The rear facing seat was moved further rearwards to accommodate equipment storage. Previously the rear facing seat back was constrained in a forward collision by its proximity to the cross bracing of the Roll Over Protective Structure.

Figure 1. Photos of Regional Forces Surveillance Vehicle (RFSV)

The placement of the rear facing seat rearwards resulted in an analysis of the seat and alternatives. The rear facing seat and commercially available alternative rear facing seats were subjected to a 20g acceleration pulse using a Hybrid III 50% adult male Anthropomorphic Test Dummy (ATD) to measure occupant decelerations.

The rear facing seat and commercially available alternative rear facing seats failed to prevent injurious loading. A soldier proof robust tapered energy attenuator was then designed to accommodate both a 5% adult female and a 95% adult male which could be positioned between the rear of the seat and the Roll Over Protective Structure. This was done so as to investigate the seat's crashworthiness for a range of possible occupants.

TESTS ON REAR FACING SEATS

In order to determine the dynamic performance of the RFSV rear facing seat, a series of dynamic sled tests on prototype seats were conducted as shown in Figures 2 to 5 [reference 1, 2].

Figure 2. Pre Test S010165 (ISRI reclining seat)

Figure 3. Post Test S010165

The first series of tests were carried out on a rigid seat. Figures 2 and 3 show the pre and post test S101165, an ISRI reclining seat without an energy absorber. The seat incorporated a reclining system (operated by means of a spring-loaded self-locking release mechanism) which was reclined to produce a seat back angle of approximately 76°. This seat was tested in conjunction with a backrest stopper mounted onto the test rig's bulkhead. The stopper was designed to limit the amount of deformation of the seat back.

The second series of tests were carried out on modified seats where the seat back was supported by an energy absorber as shown in Figures 4 and 5. The backrest stopper was removed and replaced by an energy absorber. The head restraint incorporated a mild steel plate three millimetres thick within the seat's foam padding.

The test method was based on the dynamic test requirements of Australian Design Rule 68/00 "Occupant protection in buses" [reference 3]. The Hybrid III test dummy, although designed for frontal impact, was used to assess the seat strength, the occupant restraint system and injury protection provided.

Figure 4: Pre test S010287 (old ISRI seat)

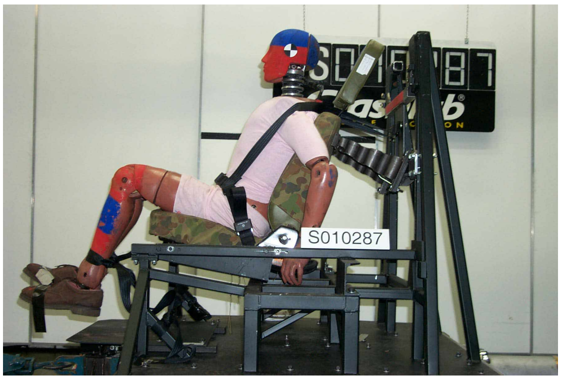

Figure 5: Post test S010287

The test rig used for all tests was fabricated from square tubular steel to position the test seats on the sled. The rig incorporated attachment fittings for the seat (by means of designated attachment frames to enable different mounting configurations), anchorage points for the occupant restraint system, bulkhead and floor. A foot support section mounted to the rig's floor was raised by approximately 30 mm to enable the test dummy's feet to be placed flat on the floor.

The energy absorber was mounted to the test rig's bulkhead directly behind the seat back at an angle of approximately 67° to the vertical and was required to absorb the loads during impact [see figure 4]. The system consisted of two tapered mild steel sections approximately 300mm long, incorporating a series of folds as shown in Figure 6. The taper was 30mm wide directly behind the test seat and 90 mm wide at the bulkhead mount giving a 30:90 configuration. A static compression test was carried out in the laboratory and its load-deflection curve is presented in Figure 7.

Figure 6. Photo of the energy absorber

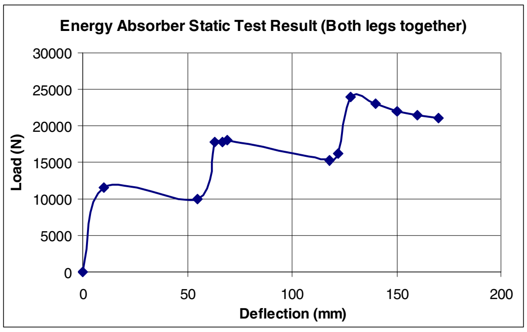

Figure 7. Energy absorber load deflection test curve

Figures 1 and 3 show the test setup. A Hybrid III test dummy was positioned in the test seat and the system subjected to the dynamic impact pulse shown in Figure 8. Australian design Rule 68/00 "Occupant Protection in buses" Clause 7.4 requires a velocity change of not less than 49 km/h and a forward deceleration of at least 20 g's (196 m/s^2) to be achieved within 30 ms.

The occupant restraint system used with the seats was a four point harness system. The harness is comprised of two shoulder belts each incorporating an emergency locking retractor (ELR) that is mounted to the rig's bulkhead directly behind the seat. The shoulder belts were joined to a manually adjusted lap belt mounted to the seat.

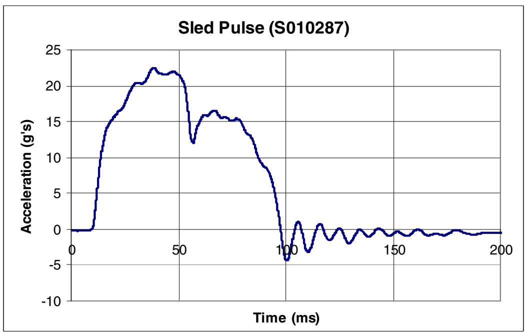

Figure 8: Sled deceleration pulse used for test S010287

The test results of the Hybrid III acceleration measurements are summarised in Table 1. It should be pointed out that any injury severity parameter for the Hybrid III was not calculated for the test because the Hybrid III test dummy has validated bio-mechanical responses for frontal impacts only.

Table 1: Hybrid III acceleration measurements

	S010165	S010287
Head (g's) - x	455	56
- y	9	2
- z	97	37
Resultant (max)	465	58
Chest (g's) - x	68	43
- y	7	3
- z	19	8
Resultant (3ms max)	66	39
Energy Absorber deformation (mm)	N/A	33

The high speed film of test S010165 shows the dummy sliding back into the seat towards the direction of impact, where it began to load the seat back approximately 25 ms after impact. The gradual loading of the seat back resulted in impact with the backrest stopper at approximately 50ms, which in turn loaded the chest substantially throughout the event. A 3ms resultant chest acceleration of 66 g's was measured. The head restraint contacted the upper section of the bulkhead at approximately 55ms where it started to deform. At approximately 65 ms the back of the head contacted the upper half of the head restraint as a result of neck extension resulting from the impact event. Compression of the head restraint's padding cushioned the impact between the head and upper section of the bulkhead producing a maximum resultant acceleration of 465 g at around 72 ms.

For test S010287, the high speed film shows the dummy sliding back into the seat towards the direction of impact. The dummy then started to load the seat back at approximately 30ms followed by loading of the energy absorber at approximately 35 ms. The energy absorber appeared to undergo loading for a further 35 ms with the deformation being reasonably uniform on both sides. The back of the head contacted the centre of the head restraint at approximately 45 ms after impact. The foam padding then began to compress. The impact of the back of the head with the head restraint gave a maximum resultant head acceleration of 58 g's at around 56 ms. A 3 ms resultant chest acceleration of 39 g's at 51 ms was also noted.

Test results clearly show a significant improvement when test S010287 is compared to test S010165 in term of occupant response. It proved that by incorporating an energy absorber into a rear facing seating system, occupant safety can be dramatically improved.

OCUPANT DYNAMIC SIMULATION

It has long been recognised that computer simulation can be an effective and relatively low cost tool to analyse design alternatives or to carry out detailed parametric studies of the crashworthiness performance of a mechanical system [4-9]. The use of suitable computer models to assist in the development of prototypes or to improve a particular design can also reduce the amount of costly physical testing.

The main objective of this project was to develop a capability to simulate occupant dynamics in a rear facing seat under a frontal impact situation. These simulations can then be utilised to determine peak occupant decelerations and injury values for different dummy sizes, providing information for seat design.

The MADYMO computer package was chosen to simulate the occupant dynamics [ref. 10-13]. In this study, a 50% male Hybrid III dummy was used to simulate and develop the energy absorbing seating system.

MADYMO Model

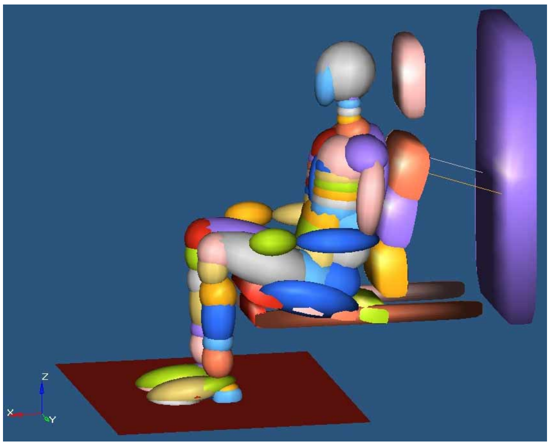

Figure 9. MADYMO Model setup

In constructing the MADYMO model, the seat/rig geometry, occupant properties (segment geometry, inertial properties, and joint properties), and occupant/seat contact interaction properties had to be specified. The belt restraint system was not modelled because it had little influence on the occupant dynamic behaviour for this particular application.

Seat/rig Model. The seat setup shown in Figure 9 was modelled as a multi-body system, consisting of a seat base, seat back and head rest. The seat was constrained to the rig's rail by using the point-restraint feature. The floor was modelled as a plane.

Energy Absorber Model. Maxwell spring elements were used to model the energy absorber with an initial length of 300 mm. The stiffness values from the laboratory test presented in Figure 6 were incorporated into the model.

Occupant Model. The occupant properties were based on the Hybrid III anthropomorphic crash dummy. The MADYMO library contains a standard data set which characterises the dynamic behaviour of the Hybrid III dummy in a frontal crash, but can also be used for such rearward simulation. A rearward impact dummy (RID) is not available as yet. Geometric, inertial and joint properties were obtained from various measurement data, including static and pendulum tests (refs 10-11). The dummy was positioned in the same way as in the test setup shown in Figure 4.

Occupant/Seat & Rig Interaction. By representing body segments and seat/rig components as ellipsoids and planes, the MADYMO algorithm models the interactions for ellipsoid-ellipsoid and plane-ellipsoid contacts according to the contact parameters specified by the user, which include stiffness, hysteresis and friction.

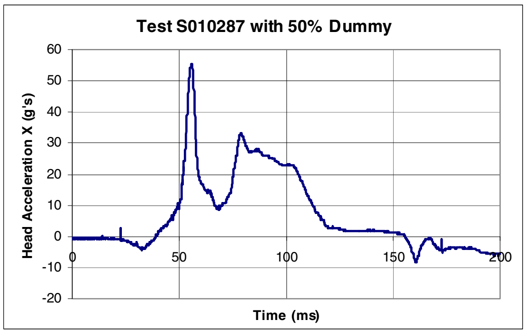

Figure 10. Head frontal (x) acceleration

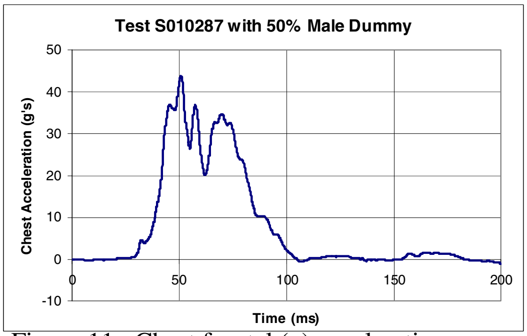

Figure 11. Chest frontal (x) acceleration

Model Validation. Once the MADYMO model was developed, it was then calibrated against the crash test S010287 described in the last section. In the calibration process attention was focussed on the head and chest acceleration in the axial direction and maximum compression of the energy absorber. In particular, head and chest acceleration in the axial direction [Figures 10 and 11] from the test were used as the benchmark in the calibration process. The simulation results obtained for both occupant head acceleration (Figure 12) and chest acceleration (Figure 13) matched the test results with satisfactory accuracy. The peak acceleration and the energy absorber deformation are a very good match to the test measurements as shown in Table 2.

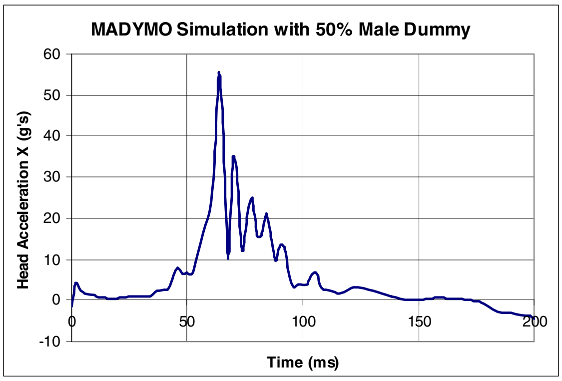

Figure 12. Head frontal (x) acceleration from MADYMO simulation

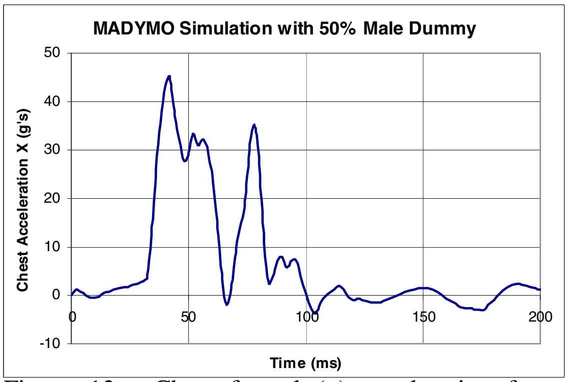

Figure 13. Chest frontal (x) acceleration from MADYMO simulation

Table 2: Hybrid III acceleration measurements

	Test S010287	MADYMO Simulation
Head (g's) - x	56	55
Chest (g's) - x	43	45
Energy Absorber deformation (mm)	33	33

SIMULATON RESULTS

A total of three impact simulations were performed. These consisted of three different sizes of occupants including a 50% male dummy, a small 5% female hybrid III dummy and a large 95% male hybrid III dummy. All three dummies were placed in the same seating position and subjected to the same crash pulse. Tables 3 and 4 list the predicted responses for the different size occupants. Table 5 summarises the deformation of the energy absorber.

Table 3. Peak Occupant Acceleration Results

Dummy Type	Head Resultant Acceleration (g)	Chest Resultant Acceleration (g)
50% Male	62	47
95% Male	57	56
5% Female	92	51

Table 4. Occupant Injury Results

Dummy Type	Head Injury Criterion (HIC)	Upper thorax 3ms maximum (g's)
50% Male	232	42.4
95% Male	239	38.3
5% Female	324	48.6

Table 5. Energy absorber deformation.

Dummy Type	Energy Absorber deformation (mm)
50% Male	33
95% Male	43
5% Female	11

50% male occupant impact. During dynamic simulation the occupant slid back into the seat towards the direction of impact. It commenced to load the seat back at approximately 30 ms, followed by loading of the energy absorber at approximately 35 ms (Figure 14). The seat was continually loaded up until approximately 110 ms when the dummy started to slide off. The back of the head contacted the centre of the head restraint at approximately 50 ms after impact. The impact of the back of the head with the head restraint gave a maximum resultant head acceleration of 62 g's at 64 ms (Figure 15). The maximum resultant chest acceleration was 47 g's (Figure 16). The corresponding HIC was 232 (Table 4). The computed 3-ms chest acceleration was 42 g's. The impact resulted in the energy absorber system deforming 33 mm.

95% large male occupant impact. The kinematics of the large size occupant is similar to that of the 50% dummy, except the dummy loaded more into the seat. The dummy commenced to load the seat back at approximately 30ms followed by loading of the energy absorber at approximately

35 ms (Figure 14). The seat was continually loaded until approximately 130 ms when the dummy started to slide off. The maximum resultant head and chest acceleration computed were 57 g's and 56 g, respectively (Figures 17&18). The calculated HIC was 239 (Table 4). The computed 3-ms chest acceleration was 38 g's. It was predicted the energy absorber would deform 43 mm when subject to the impact load.

5% small female occupant impact. As expected, the small female occupant loaded into the seat much more lightly than the male occupants, although its dynamic response to the same crash pulse was similar to that of the large male occupants. However, the injuries calculated were the largest among the three for the small female ATD. The HIC was 324 and 3-ms chest acceleration was 49 g's. Figure 19 and 20 show the head and chest responses for the simulated crash. The deformation of the energy absorber was only 11 mm.

Overall, by using the energy absorbing seating system, the occupant peak acceleration for all three occupant sizes is much lower than that when a conventional seating system is used (Table 1). Occupant injuries are small to moderate.

CONCLUSIONS

A MADYMO model was developed and validated for a rear facing seat in frontal crashes. Three simulations were performed based on a 50% average male Hybrid III dummy, a 95% large male dummy and a 5% small female dummy to cover the range of occupant sizes. Occupant safety has been assessed through simulations.

The results of the simulations showed that by using an energy absorbing seating system, crash deceleration can be effectively attenuated and occupant injuries significantly reduced in comparison to conventional seating systems.

In future, physical crash tests will still be required as the final certification method for approval of a particular crashworthy mechanical system. However during the development process the application of computer simulation methods as presented in this paper show that it is possible to reduce development costs.

ACKNOWLEDGEMENTS

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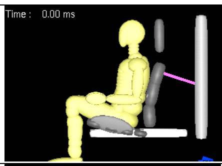
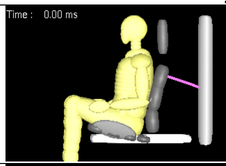
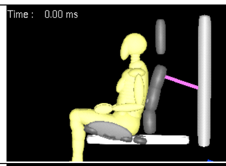
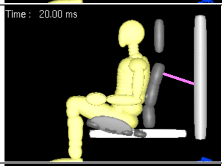
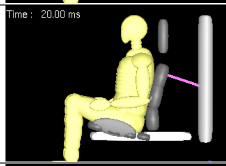
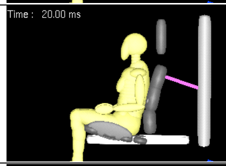
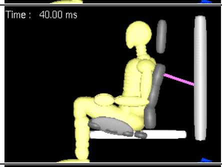
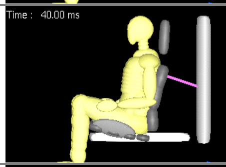
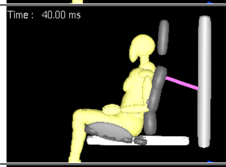
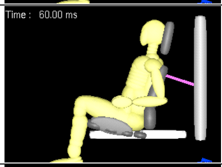
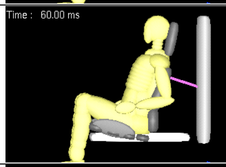
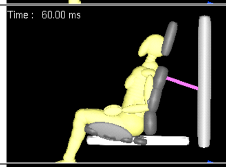
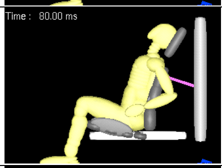
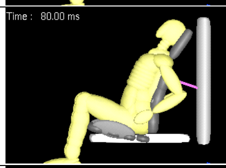
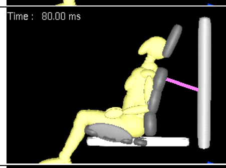
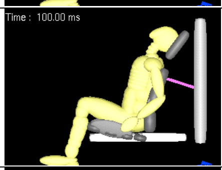
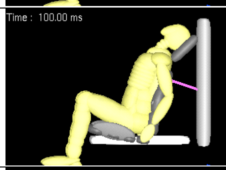
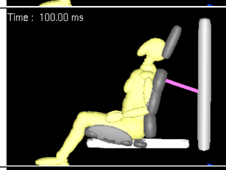
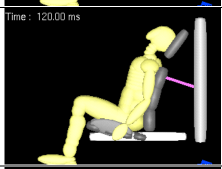
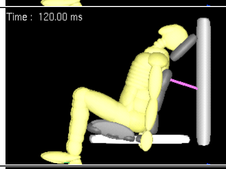
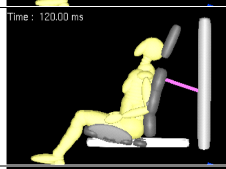
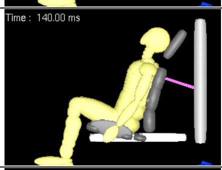
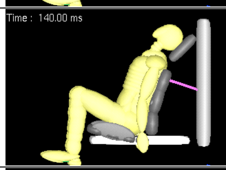
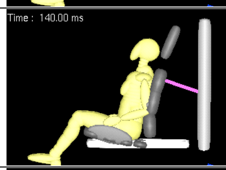
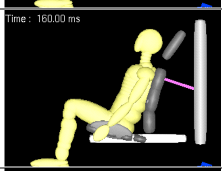
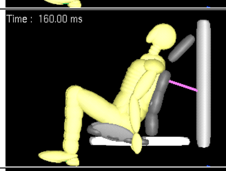
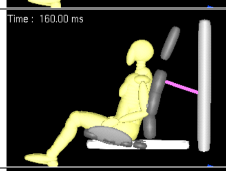
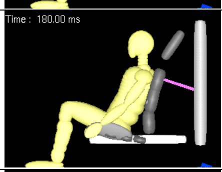
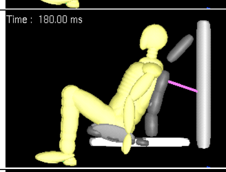
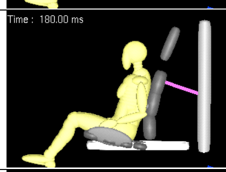
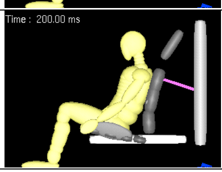
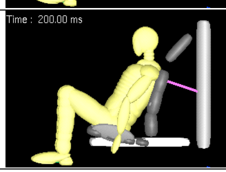
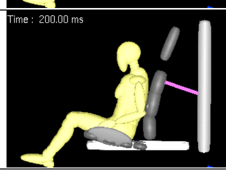
00			
20			
40			
60			
80			
100			
120			
140			
160			
180			
200			

Figure 14: Dummy Kinematics during impact

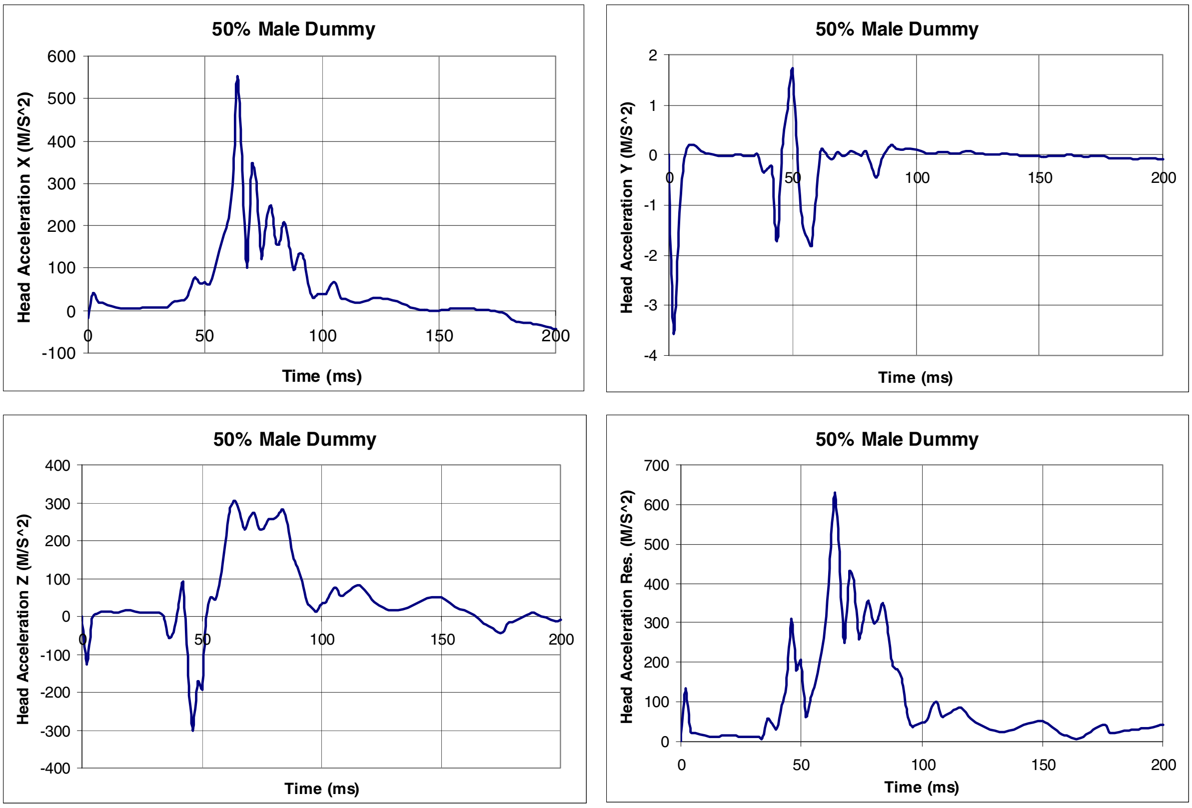


Figure 15. Head acceleration plot for 50% male dummy from computer simulation

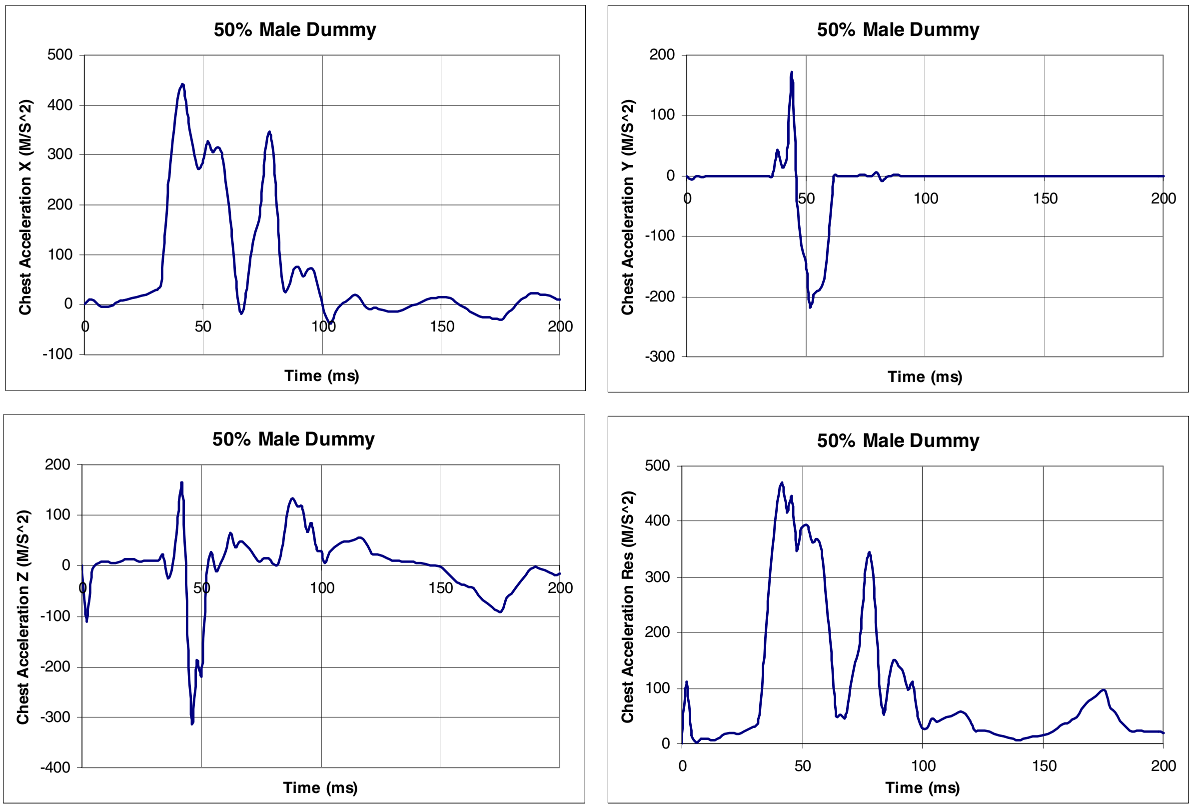


Figure 16. Chest acceleration plot for 50% male dummy from computer simulation

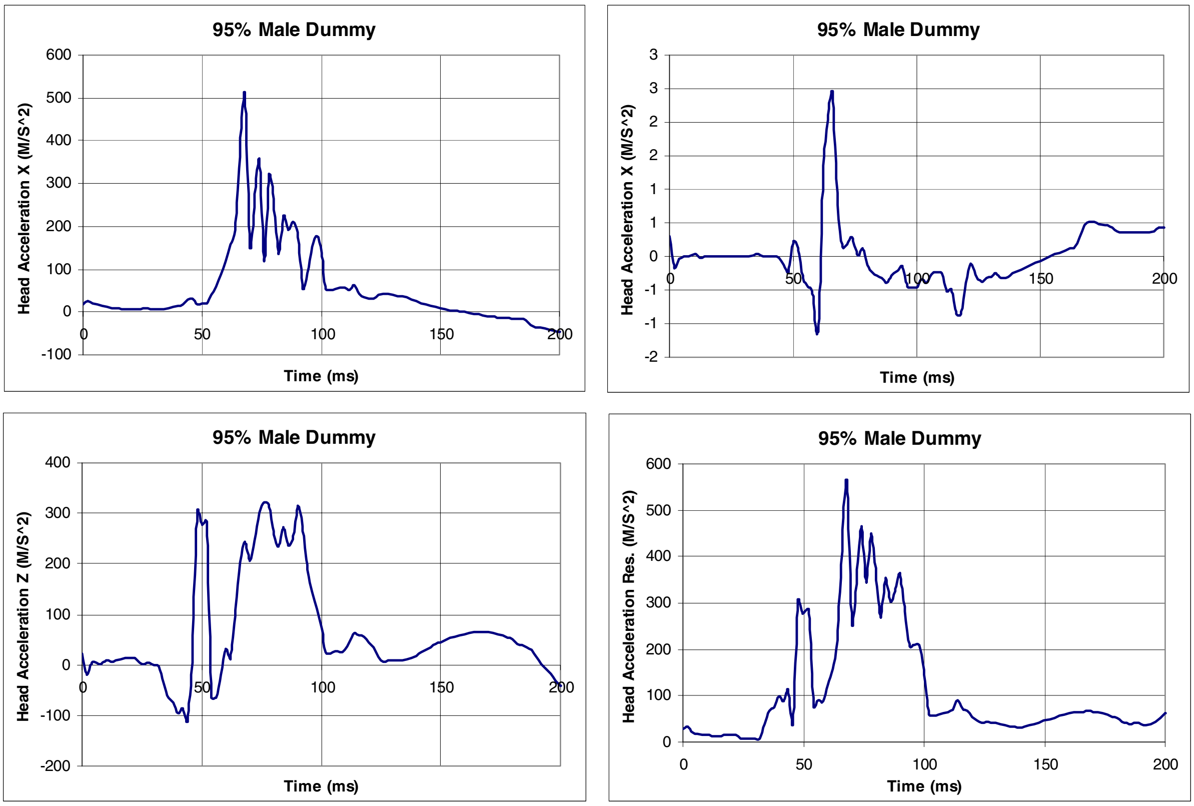


Figure 17. Head acceleration plot for 95% male dummy from computer simulation

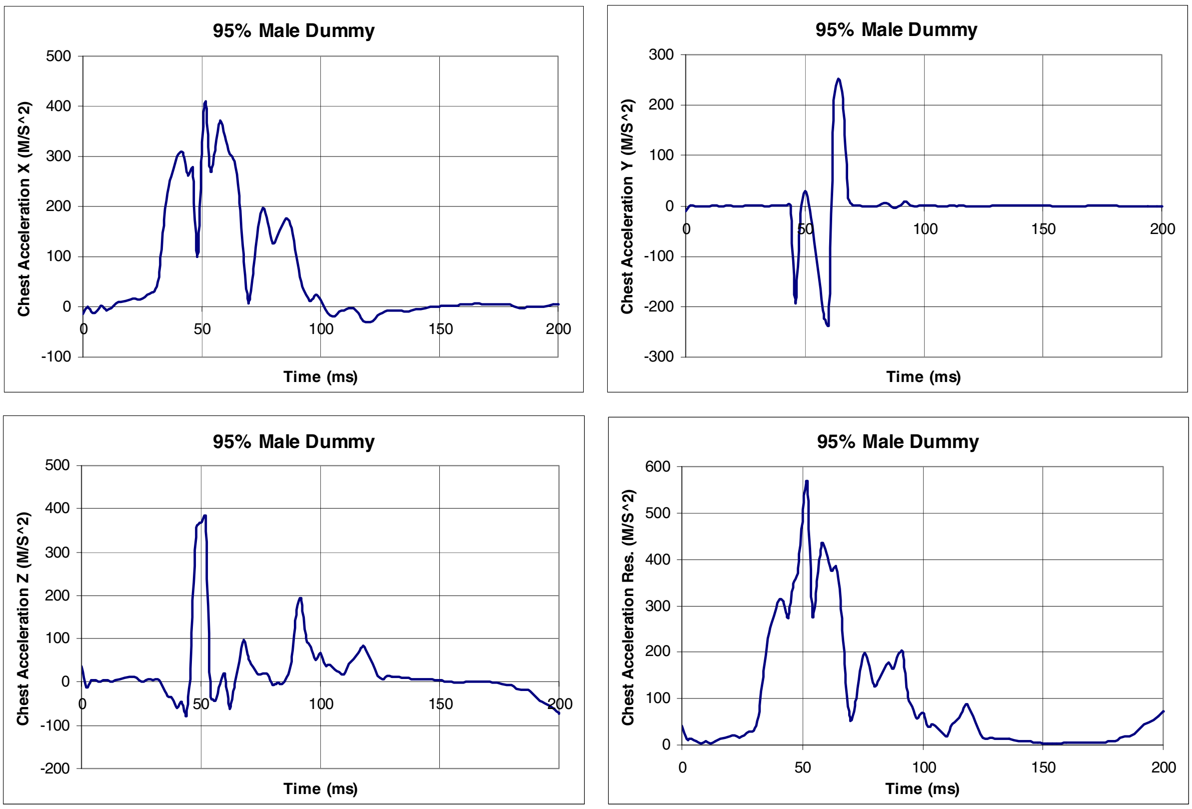


Figure 18. Chest acceleration plot for 95% male dummy from computer simulation

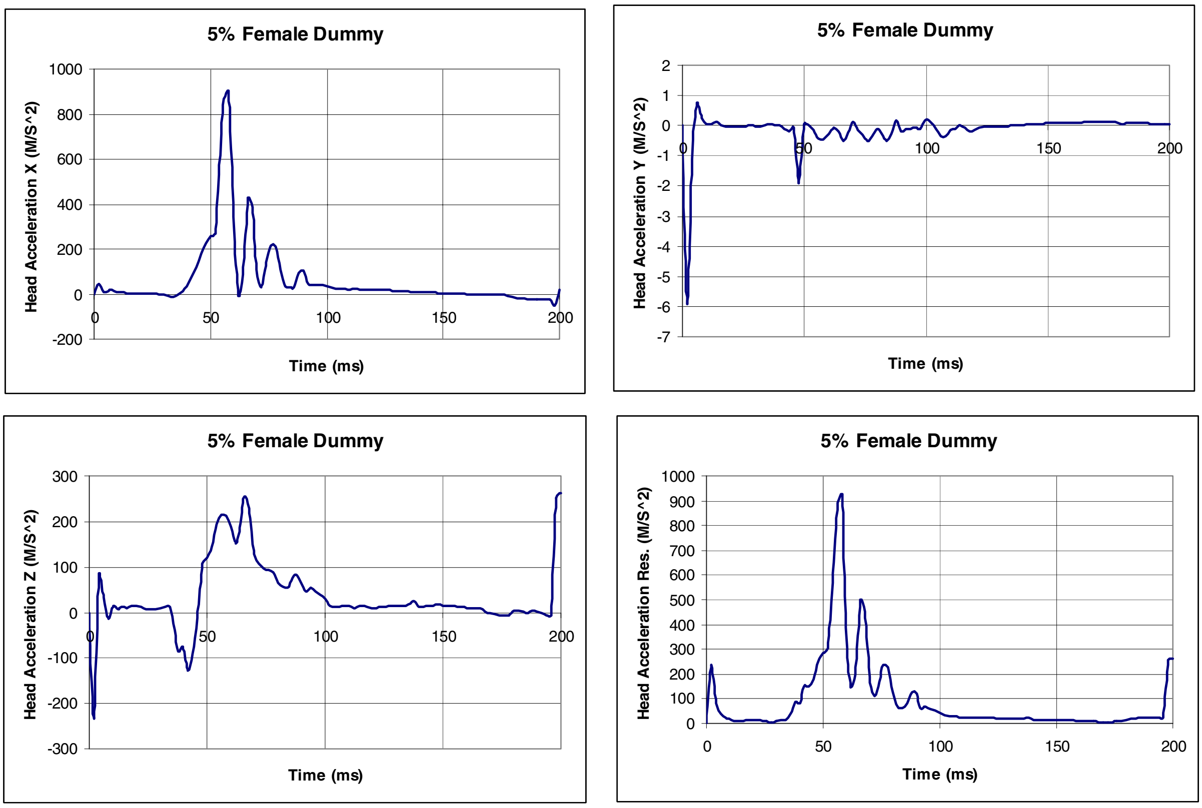


Figure 19. Head acceleration plot for 5% female dummy from computer simulation

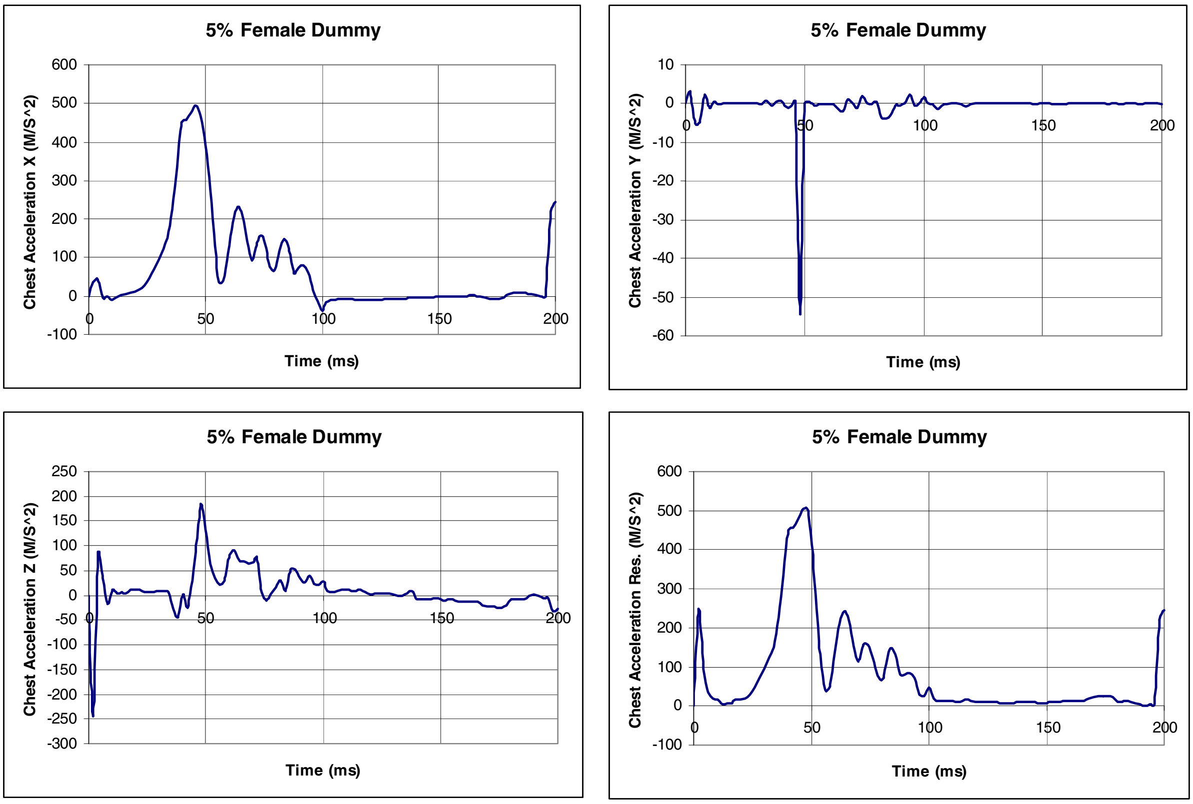


Figure 20. Chest acceleration plot for 5% female dummy from computer simulation